Inter-laminar Insulation Faults Detection and Quality Assessment of Magnetic Cores Using Flux Injection Probe

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***Abstract*- Inter-laminar faults between laminations of the magnetic cores increase core losses and could cause major damage to electrical machines. A system has been developed to detect inter-laminar fault between the laminations of the magnetic cores by means of Flux Injection Probe (FIP). Experimental work was carried out to calibrate the measuring system and qualify its accuracy over a wide measurement range. Application of a prototype FIP to quality assessment of transformer laminations was investigated in two stages: inspection of stack of laminations with known inter-laminar faults applied by artificial shorts and inspection of stack of laminations with unknown quality. The experimental results show that the developed system is capable to detect inter-laminar fault between as few as 2 laminations.**

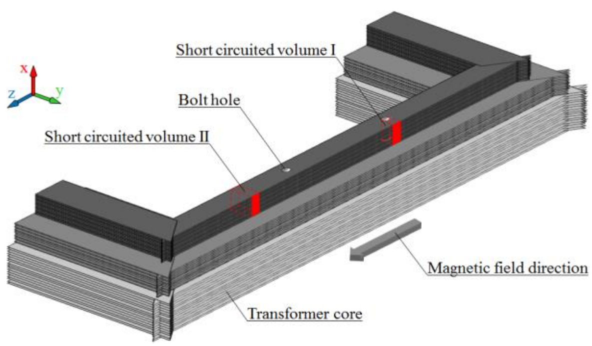
Index Terms: Inter-laminar fault, edge burr, fault detection, magnetic lamination, flux injection probe, magnetic loss.

I. Introduction

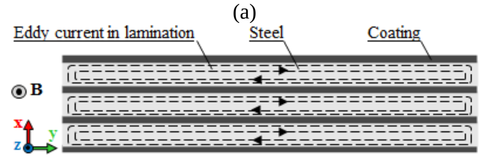
MAGNETIC cores of the electrical machines and other magnetic devices are constructed from stacks of electrical steel laminations, typically 0.23~0.5 mm thick. Since the magnetic cores are exposed to time-varying magnetic fields, eddy currents are induced in the individual laminations and consequently, energy is converted into heat in the resistance of the eddy current path [1]. The laminations are insulated from each other by means of insulating varnish or other materials to prevent electrical conduction between the laminations and limit the induced eddy currents to the individual laminations, rather than the whole core [2-3]. However since the materials used for the inter-laminar insulation are susceptible to decline and damage, short circuits between the laminations due to electrical failure could happen due to a number of reasons listed in the following [4-6]:

- Manufacturing defects in laminations, known as *burrs*.
- Mechanical damage on sides of the stacks during assembly, winding and inspections.
- Foreign particles introduced during assembly, inspection, and repair; e.g. nut, bolt and broken lamination.
- Heat and chemical factors or mechanical forces applied when stripping winding during rewind.
- Stator-rotor rubs during assembly and operation.
- Vibration of loose windings and laminations.
- Arcing from winding failure.

Inter-laminar short circuits created by one of the reasons above, lead to circulating eddy current between the defected laminations, which is larger than normal operation [6-8]. This current is the inter-laminar fault current and the created current loop is the fault current loop [9]. Typically fault current loops are formed between the shorted laminations and fault points which are perpendicular to the direction of the flux. Inter-laminar fault, which lead to inter-laminar fault current, is one of the most serious concerns of the manufacturers and customers of the electrical steels [5-11]. Fig 1-a shows a perspective view of a transformer limb with two possible inter-laminar faults in the top step. Short circuit I is formed between two sides of the core and short circuit II is formed between bolt hole and side of the core. Eddy current distribution in the laminations without fault and inter-laminar fault current in presence of the faults, from cross section view of Fig 1-a, are shown in Figs 1-b, 1-c and 1-d, respectively.



(a)



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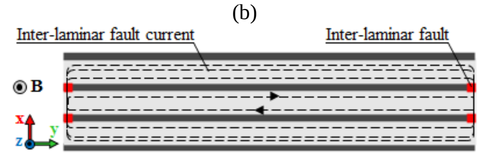

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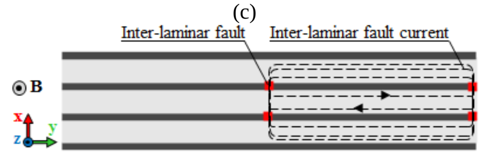


(d)

Fig 1 (a) Perspective view of a transformer limb with inter-laminar short in the top step (b) Eddy current path in the laminations without inter-laminar fault (c) and (d) Inter-laminar fault current path with inter-laminar fault

In Fig 1-c fault current loop is formed by the fault points on either sides of the laminations and shorted laminations; while in Fig 1-d fault current loop is formed by the fault points at the bolt hole, one side of the laminations and shorted laminations. Eddy current distribution in the shorted laminations and hence eddy current loss caused by the inter-laminar fault depends on the position of the fault points, fault current loop and number of shorted laminations. A few faults may not create a high inter-laminar fault current; but with several faults in the core the induced inter-laminar fault currents could be large and cause excessive local heating in the damaged area [10].

Various methods have been developed to detect inter-laminar faults in magnetic cores, which have been used in research and industrial works [4-8] and [10-12]. In almost all of these techniques the magnetic cores under test are magnetised either totally [10-12] or locally [4] and a signal is measured resulting from the injected flux to detect possible inter-laminar faults. The difference between different methods is related to the measured signal and the sensor which is implemented to measure the fault signal. In the past, detection of the hot spots in stator cores of rotary machines was done qualitatively by turning off the power and immediately crawling into the bore and feeling the surface [4]. Core quality assessments were later done using an infrared camera set inside the machine, known as *full flux ring test method* or *loop test method* [7]. In this method, an external winding is wound around the yoke of the core to excite the magnetic core at 80~100 % of rated flux. After the magnetic core heats up, a thermal camera is used to detect hot spots in the core due to possible inter-laminar fault currents. Requirement for a power-full power supply to provide the nominal flux in the core, difficulty of detecting deep-seated faults, expensive thermal sensing equipment, and safety issues are the major drawbacks of this method [7].

In 1978 **El**ectromagnetic **C**ore **I**mperfection **D**etector (EL CID) as a low-flux test was invented to detect inter-laminar fault [11]. EL CID test method uses the same excitation configuration as the loop test, but allows testing at 3~4 % of rated flux level, which significantly reduces the power requirement and safety risks [7]. In this test a flux sensing probe, including an air core coil of many turns bent into a "horse shoe" shape known as Chattock Coil or Maxwell Worm, is scanned in the axial direction along the surface of the core to detect irregular flux patterns caused by inter-laminar fault current [6]. In 2004 another electro-magnetic method was proposed in which the magnetic core is magnetised locally by means of a **F**lux **I**njection **P**robe (FIP). The measured power loss of the magnetised zone, also known as test zone, being indicative of the condition and quality of the test zone [3] and [5]. In the absence of inter-laminar fault in the test zone, the measured power loss corresponds to the normal loss. However, in the presence of an inter-laminar fault in the test zone, an increase of the value of the power loss can be observed [5].

Almost all of the existing techniques were basically developed for stator cores of generators, but they could be modified and re-designed for transformer cores or other magnetic cores. The aim of this paper is to develop a non-destructive experimental technique to detect inter-laminar faults and study of the quality of the transformer cores using a flux injection probe. A prototype model of FIP was developed to magnetise the cores locally and to detect inter-laminar faults between the laminations. Quality of stacks of GO laminations with well-known faults, applied by artificial short circuits, and unknown faults were investigated using the prototype FIP.

II. PRINCIPLE OF FLUX INJECTION PROBE

A usual method to magnetise the magnetic cores locally is to inject magnetic flux into the core using a C-shaped (or U-shaped) core including an excitation winding. This magnetic core is known as **F**lux **I**njection **P**robe (FIP) [5]. Applications of FIP to magnetise a stator core and a 5 stacks transformer core locally are shown in Figs 2-a and 2-b, respectively.

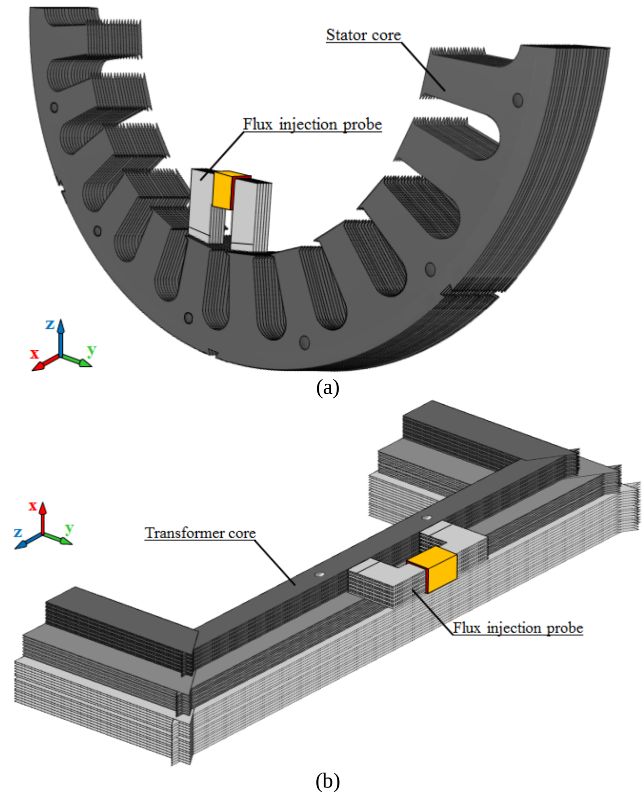


Fig 2 Perspective view of (a) an stator core and (b) a transformer core under test by a flux injection probe

Fig 2 shows that magnetic circuit of the FIP closes through that part of the core placed between the two prongs of the probe. This part of the magnetic core is known as *test zone* or *magnetised zone* [5]. In order to specify the magnetic circuit of the FIP and visualise the distribution of the injected magnetic field in the core, 2-D FEM simulations were performed using COMSOL Multiphysics. The results for both stator and transformer cores are shown in Figs 3-a and 3-b, respectively.

In the relevant test methods, all regions of the magnetic core should be magnetised by sliding the FIP on all sides of the core. An electric or magnetic signal is then measured resulting from the injected magnetic flux using a proper sensor. Possible inter-laminar faults between the laminations of the magnetic core could be then detected by analysing and processing the measured signal. The measured signal could be induced voltage [5], magnetic flux [10], flux leakage [13] and etc.

III. INTER-LAMINAR FAULT DETECTION USING FIP

One of the major drawbacks of the fully magnetised inter-laminar fault detection methods is the requirement of a high level power supply to provide rated flux density in the magnetic core under test.

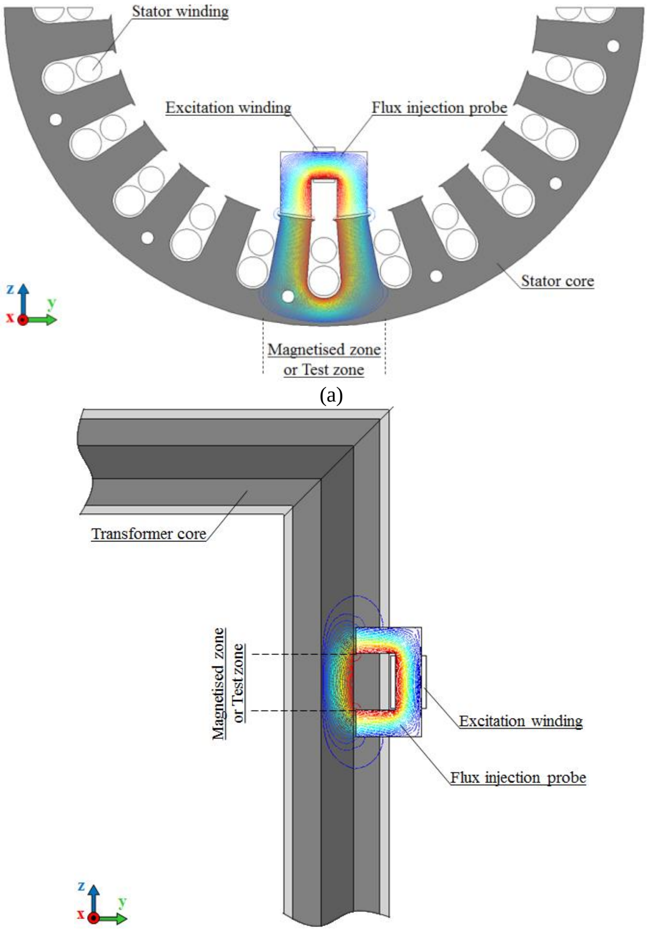


Fig 3 2-D FEM modeling of magnetic flux distribution in (a) an stator core (b) a transformer core injected by flux injection probe

Kliman *et al*. [5] proposed a low power non-destructive magnetic method to detect inter-laminar faults, particularly between laminations of synchronous generator cores. The basic idea of this method is to scan side of the magnetic core under test by the FIP and measuring magnetic loss of the magnetised zone. Therefore an extra winding, known as measurement winding, is required to measure an induced voltage resulting from the injected flux into the test zone. A schematic of an FIP with excitation and measurement windings is shown in Fig 4.

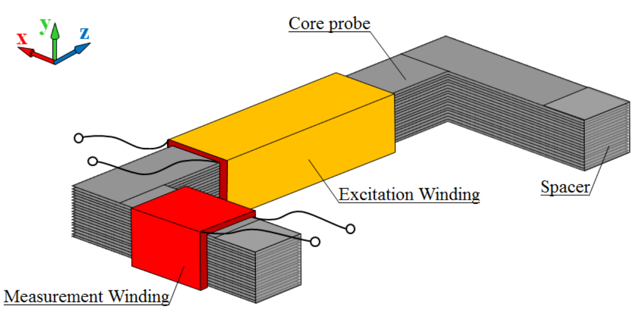


Fig 4 Schematic of an FIP with measurement winding to measure magnetic power loss

Magnetic loss measured by the FIP can be obtained by [5]:

$$p = \frac{1}{T}\int_{t}^{t+T} \frac{N_e}{N_m} v_m(t)\, i_e(t)\, dt \qquad (1)$$

where N_e and N_m are number of turns of the excitation and measurement windings and $i_e\,(t)$ and $v_m\,(t)$ are current flowing in the excitation winding and induced voltage in the measurement winding, respectively. Using the induced voltage across the measurement winding $v_m\,(t)$, instead of the voltage across the excitation winding, leads to the copper losses of the excitation winding to be eliminated in the loss calculation. The resulting power loss of (1) being indicative of the quality of the test zone in front of the probe. When the laminations are well insulated from each other, i.e. there is no inter-laminar fault between the laminations; the measured loss resulting from the injected flux is in the range of nominal loss of the core at the flux density and frequency applied by the excitation winding. However if inter-laminar faults exist between the laminations of the test zone, extra power loss caused by the inter-laminar fault can be sensed and measured by the FIP. Therefore quality of the magnetic cores could be evaluated by scanning all regions of the core and measuring instantaneous values of the injected current into the excitation winding and the induced voltage into the measurement winding. A pattern of power loss versus position of the probe can be then recorded. Irregularities in the pattern of the core loss represent inter-laminar fault at that particular point [5]. The measured power loss of the test zone can be also used to measure properties of the core under test to distinguish between the magnetic cores made of the different types of materials [14].

IV. Prototype Model of FIP and Experimental Set-up

A prototype model of FIP was developed to magnetise magnetic cores locally and detecting inter-laminar faults in the core. The Magnetic core of the probe was made of 34 layers of magnetic laminations of *HiB Fe* 3 % *Si* of 0.3 mm thick with standard grade of M105-30P. Laminations of the core were clamped together using a non-magnetic frame and nylon bolt and nut. A 328 turns winding of enameled copper wire of 1.00 mm thick was wound around the yoke as excitation winding and a 32 turns winding of enameled copper wire of 0.525 mm was wound around one prong as the measurement winding. Since sides of the core are scanned by the FIP, presence of an air gap between the ends faces of the prongs and side of the core under test is unavoidable. In order to minimise the variation of the gaps and also prevent electrical connection between the probe and the core under test, end faces of the prongs were covered by a plastic layer of 0.135 mm thick. A perspective view with physical dimensions and a photograph of the prototype FIP are shown in Fig 5-a and 5-b, respectively.

A. Block diagram of the measuring system

A computer-controlled system has been developed within the Wolfson Centre for Magnetic to measure magnetic properties of the electrical steels providing high accuracy measurements. The measuring system and principal of the loss measurement is based on the measuring system of single strip tester (SST) [15]. Fig 6 shows a schematic diagram of the system, particularly for this type of measurement. This schematic diagram comprises a PC in which LabVIEW 8.5 from National Instruments was installed, a NI PCI DAQ-6120 data acquisition card, a power amplifier, a 1 Ω shunt resistor (R_{sh}) and flux injection probe.

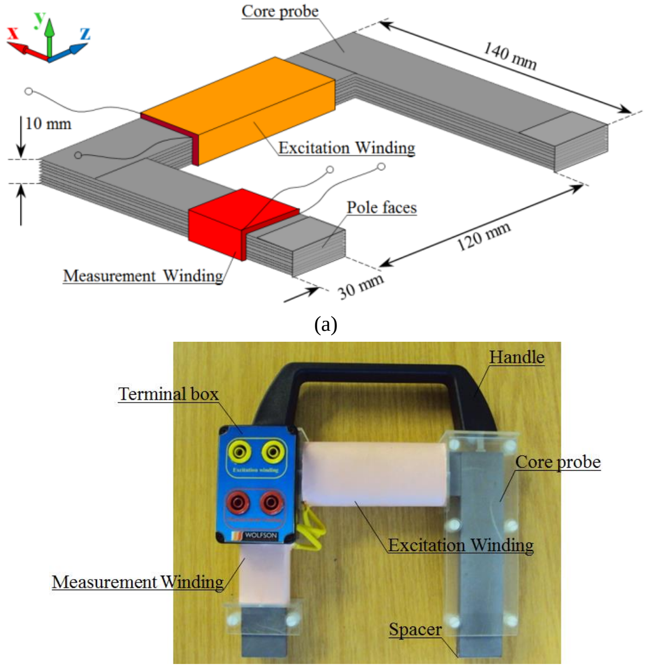


Fig 5 (a) Perspective view and dimensions (b) photograph of the prototype flux injection probe

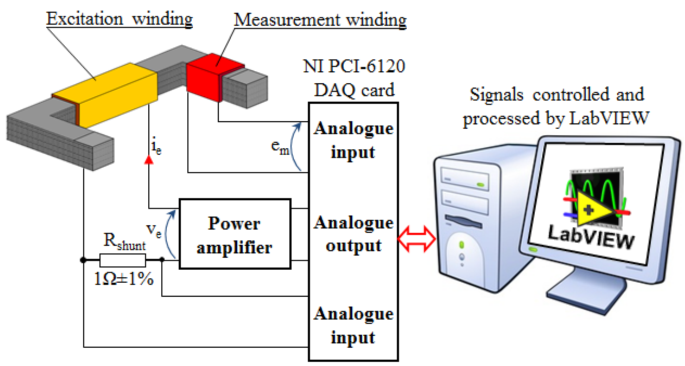


Fig 6 Schematic diagram of computer-controlled measurement system

The magnetising voltage of the excitation winding was generated by the LabVIEW program via a voltage output of the DAQ card and power amplifier. The voltage drop across the shunt resistor (R_{shunt}) and the induced voltage in the measurement winding (e_m) were read for calculation of flux density and magnetic field strength, respectively. The control of the flux density waveform was implemented in LabVIEW as shown in Fig 6. A feedback control system was used to control the flux density and secondary induced voltage waveforms to be sinusoidal. The form factor (FF) of the secondary induced voltage was maintained to be 1.111 ± 0.02 %, which is better than the value recommended in [15].

B. Flowchart of the measuring system

A flowchart was designed for inter-laminar fault detection using the FIP, as shown in Fig 7. Since power loss is directly linked to the level of the flux density ***B***, it is important to adjust this parameter at the desired levels. Therefore according to the designed flowchart, first a table of ***B*** values and the measurement criteria which are the maximum 0.02 % error of ***B*** and the ideal FF of the induced voltage in the measurement winding are read. Then, the first magnetising waveform is applied to the excitation winding of the FIP. If the criteria are met, the *b* and *h* waveforms will be averaged to minimise random errors, otherwise the magnetising waveform is adjusted by the feedback algorithm. After averaging, the criteria are re-checked then power loss of the test zone is calculated and the measurement data is saved. This procedure is repeated by positioning the FIP near the surface of the magnetic core until all regions of the core have been tested. Finally a pattern of the measured power loss versus position of the probe will plot.

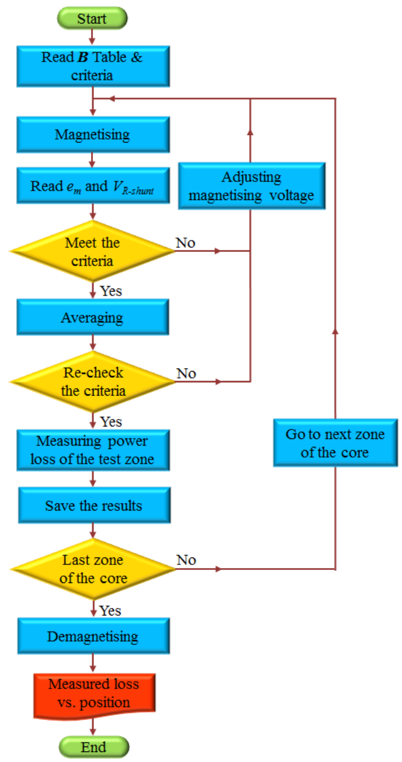
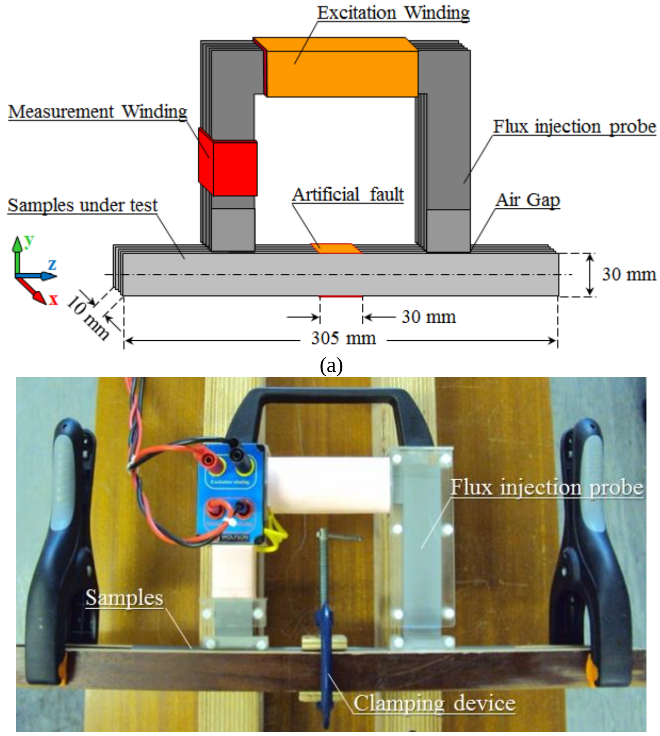


Fig 7 Flowchart of the inter-laminar fault detection by flux injection probe

C. Calibrating the measuring system

In order to calibrate the FIP and verify the accuracy of the measuring system and inter-laminar fault detection, quality of the FIP should be initially evaluated properly. A stack of 34 standard Epstein strips (30 mm wide, 305 mm long) with the same material as the FIP core was assembled. The prototype model of FIP was then placed on side of the stack. The position of the FIP and the stack under test were fixed using clamping devices during the experiments to avoid any vibrations and change in the magnetic circuit. The specific core loss of the stack was measured at peak flux densities of 0.5 T up to 1.5 T and magnetising frequency of 50 Hz. Setting of the software in the LabVIEW program was modified to calibrate the system and achieve nominal loss at each particular flux density. Laminations were then shorted together artificially on either side, using copper tape of 8 µm thick and 30 mm width and 6 different sizes of high to shorting out 5 up to 30 laminations. The copper tapes were mounted on wooden blocks and pressed against the sides of the stack of laminations and uniformly clamped using G-clamp. A Schematic diagram and a photograph of the experimental set-up are shown in Figs 8-a and 8-b, respectively.



(a)

(b)

Fig 8 (a) Schematic and (b) photograph of experimental setup of calibrating of the prototype FIP

Specific power losses versus number of the shorted laminations at different flux densities at a frequency of 50 Hz are shown in Fig 9. Power loss measurements were repeated three times at each flux density with repeatability [16] of better than 0.0135 %. The values shown in Fig 9 are the average of three measurements. In the horizontal axis of this figure, 0 represents the normal condition of the core, i.e. without applying artificial fault. The results shown in Fig 9 show that power loss increases significantly by increasing number of the inter-laminar shorts; for example specific loss at 1.5 T for normal condition of the core and applying artificial fault on 30 laminations increased from 0.893 W/kg to about 2.82 W/kg. However the increased loss from the normal operation to that of an inter-laminar fault between 5 laminations is not large enough to be measured and detected by the FIP.

The main effect of inter-laminar faults in the magnetic cores is inter-laminar fault current and hence extra eddy current loss in the damaged laminations. Eddy current loss itself is related to f^2 [1]; therefore increasing the magnetising frequency leads to increased eddy current loss and hence total power loss. An inter-laminar fault between a small numbers of laminations could therefore be detected by magnetising the core at higher frequencies. Power loss measurement of the configuration of Fig 8 was repeated at frequency of 100 Hz. The results are shown in Fig 10. In this case, total loss of the stack was increased from 2.42 W/kg in normal condition to 2.65 W/kg in the case of inter-laminar fault between 5 laminations, which the difference is high enough to be detected by the FIP.

From the results represented in Figs 9 and 10 it could be concluded that inter-laminar faults with large number of shorts could be easily detected even at low flux density and magnetising frequency. However in order to detect inter-laminar faults between a few numbers of laminations the core should be magnetised at high flux density and high magnetising frequency.

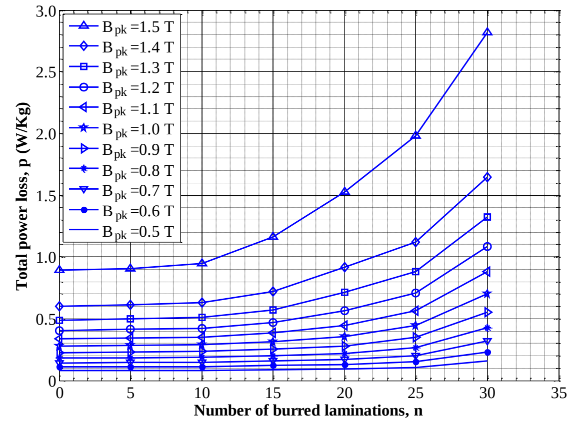


Fig 9 Specific core loss versus number of shorted laminations at different flux densities and magnetising frequency of 50 Hz

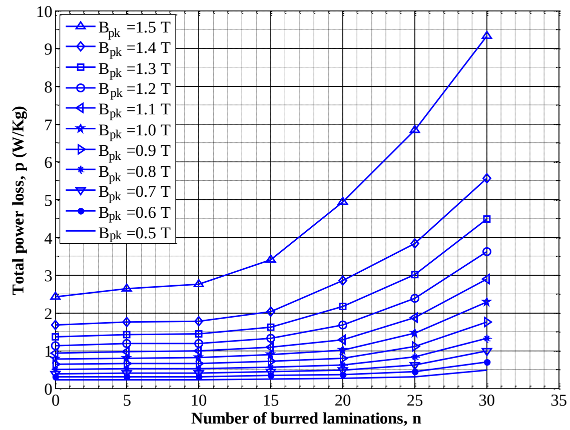


Fig 10 Specific core loss versus number of shorted laminations at different flux densities and magnetising frequency of 100 Hz

V. CASE STUDY I: QUALITY ASSESSMENT OF A STACK OF TRANSFORMER LAMINATION WITH ARTIFICIAL SHORT

The prototype model of FIP was used in a quality assessment of a real scale lamination stack. The stack, 700 mm long and 150 mm wide with 0.3 mm thick of Conventional Grain Oriented (CGO) *Fe* 3 % *Si*, was assembled to make a high of 10 mm. An artificial short circuit was introduced in the stack in two different stages:

A. Inter-laminar short on either sides of the stack
B. Inter-laminar short between one side and bolt hole

A. Artificial faults on either sides of the stack

In the first part of this study artificial fault made from copper tape of 8 µm thick and 30 mm width were applied on either side of the stack at the centre position at 3 different stages to form a short circuit between 10, 20 and 30 laminations. A schematic and photograph of the experimental setup is shown in Figs 11-a and 11-b, respectively. The stack of magnetic laminations was then magnetised by injecting magnetic flux using the FIP based on the flowchart of Fig 7. Side of the stack was scanned by sliding the FIP and power loss of the test zone was measured at positions of 10 mm.

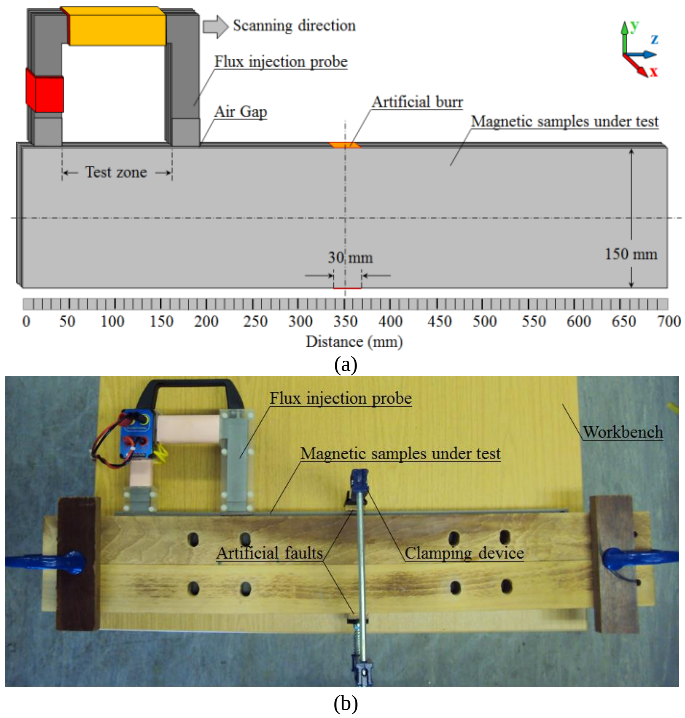


Fig 11 (a) Schematic and (b) photograph of the experimental setup of inter-laminar fault detection applied on opposite sides of a stack of transformer core laminations by FIP

A pattern of the measured loss versus axial position along the core side was plotted at each experiment. The results of the measurement with applying faults between 10, 20 and 30 laminations at flux densities of 1.0 T up to 1.4 T and frequency of 50 Hz are shown in Figs 12-a to 12-c, respectively. The magnetising frequency of the injected flux was then increased to 100 Hz when inter-laminar fault was applied to shorting up 5 laminations. The result is shown in Fig 13. Figs 12 and 13 show that power losses of the stack without inter-laminar fault correspond with the nominal loss of the steel and power loss at the faulted zone is higher than the no-fault zones. Increased power loss in the profile of the power loss indicates the presence of inter-laminar faults at that zone. Power loss of the faulted zone increases by increasing number of the shorts which is one of the major factors in determination of power loss of the defected zone [1].

B. Artificial fault between one side and bolt hole

In the next part of this work inter-laminar fault was applied between one side of the core and bolt hole. 10 mm diameter holes were punched at the center of the laminations by electric discharge machining (EDM). A schematic of the experimental setup, position of the bolt hole and a photograph of the FIP near the bolt hole are shown in Figs 14-a to 14-c, respectively. Experiments were performed at the same flux densities, frequencies and under the same procedure as session A. The results are shown in Figs 15 and 16.

The same notes as session A could be concluded from Figs 15 and 16; however specific power loss of the faulted zone of Fig 14 is less than the result of Fig 11 for the same number of shorted laminations, injected flux density and frequency. The reason is basically related to the electrical resistance of the fault current loop. There are two different fault current loops for the setups of Figs 11 and 14. In the setup of Fig 11 fault points of the fault current loops are formed by the copper tapes of 30 mm width, while in the setup of Fig 14 one side of the fault loop is formed by a narrow strip of copper of approximate width of 15.7 mm (half of the bolt hole circumstance). The later creates higher resistance in the fault current loop and leads to lower eddy current and hence eddy current power loss in the damaged zone of the magnetic stack.

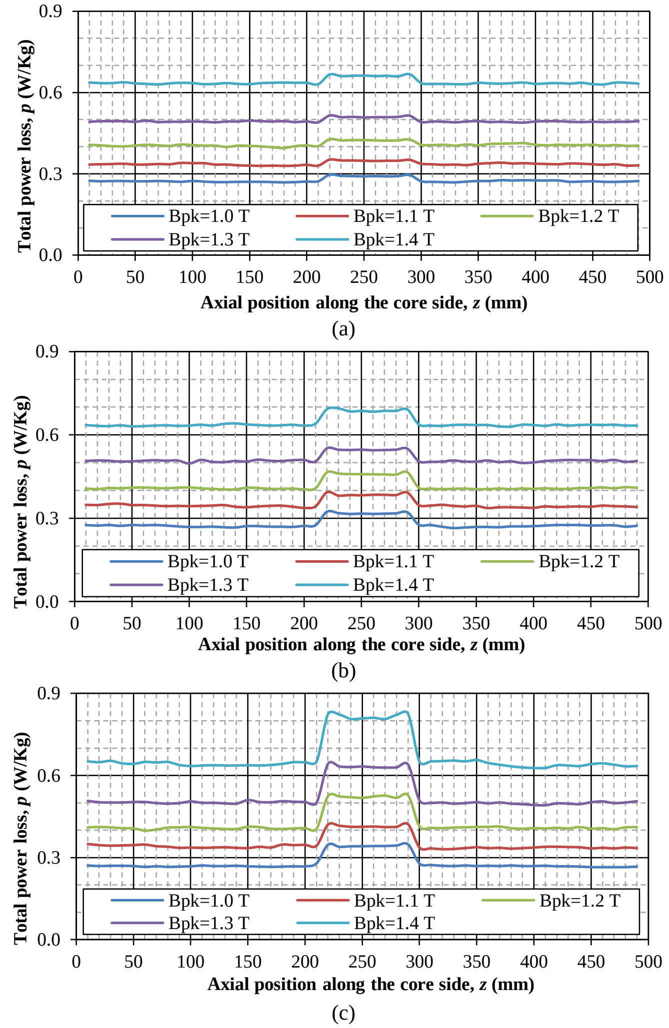


Fig 12 Specific core loss versus axial position along the core side with (a) 10 inter-laminar shorts (b) 20 inter-laminar shorts (c) 30 inter-laminar shorts on either side of stack of transformer laminations at 50 Hz

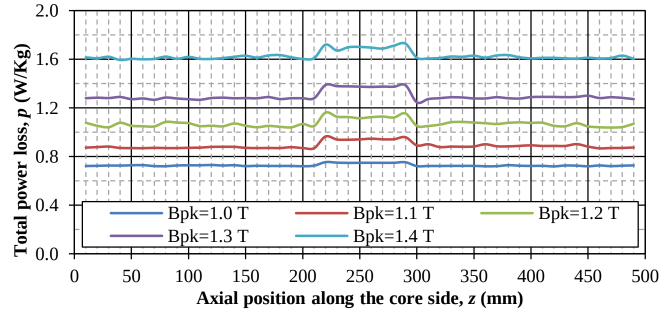
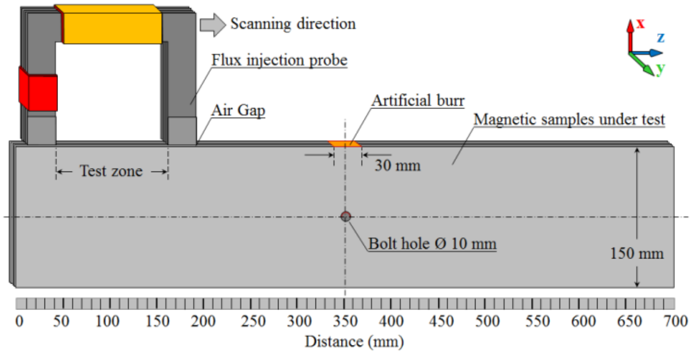
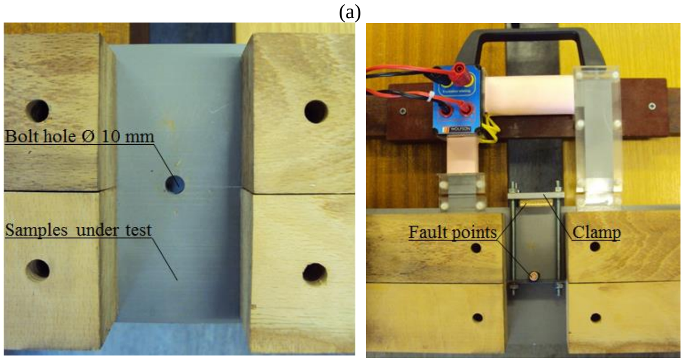


Fig 13 Specific core loss versus axial position along the core side with 5 inter-laminar shorts on either side of the stack at 100 Hz



(a)



(b) (c)

Fig 14 (a) Schematic diagram (b) stack of laminations with a 10 mm diameter hole at the centre (c) experimental set-up of inter-laminar fault detection between one side and bolt hole of a stack of transformer core laminations by FIP

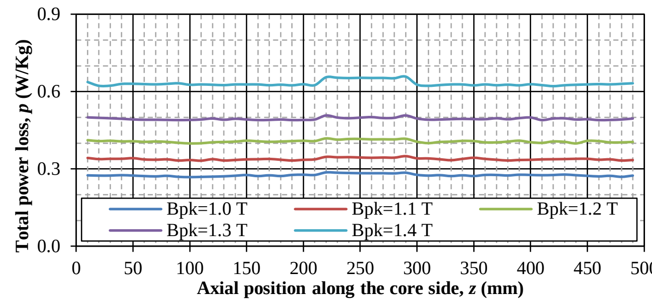
VI. Case Study II: Quality Assessment of a Stack of Transformer Lamination with Un-known Quality

In the last part of this work, quality of two different types of magnetic materials was assessed using the prototype model of FIP. Two coils of GO steel were provided by Cogent Power Ltd. with standard grades of M095-27P (coil A) and M105-30P (coil B). Each coil was cut in dimensions of 700 mm long and 150 mm wide. Stacks of 10 mm high were then assembled using each sample. Quality of the stacks was then assessed in terms of inter-laminar short circuit fault based on the flowchart of Fig 7. The experiments were carried out in two stages:

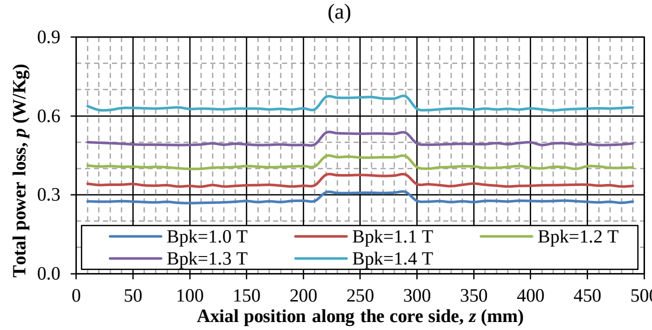
A. Scanning each side of the stacks in normal condition
B. Scanning one side while other side is shorted artificially

Possible inter-laminar fault current loops could be detected in the first stage of the experiment and single shorts between the laminations could be detected in the second stage. In stage B, similar to sections IV and V, artificial short was applied alongside of the stack of lamination using 8 µm thick copper tape mounted on a wooden block and pressed uniformly on side of the stack.

Experimental results of the stage A showed that power losses of both stacks were almost constant along the axial position of the stack and correspond with the nominal loss of the material. Therefore potentially no fault current loop was found in the stacks. However elevated power loss at position of 390 mm to 490 mm on side 1 of the stack A was found when the other side was shorted artificially, as shown in Fig 17. Therefore it could be concluded that inter-laminar faults between the laminations of coil A on side 1 is possible. To investigate this issue, side 1 of the stack A was imaged using a microscopic digital camera with resolution of 32 megapixels. The results typically at positions of 300 mm and 350 mm as two points with normal losses and positions of 400 mm and 450 mm as two points with elevated losses are shown in Figs 18-a to 18-d, respectively. Figs 18-a and 18-b show that the laminations are isolated properly at positions of 300 mm and 350 mm; while Figs 18-c and 18-d show inter-laminar short between laminations number 5 and 6 at positions of 400 mm and 450 mm. In order to show the inter-laminar fault between the suspected laminations of 5 and 6, side view of the stack at positions of 400 mm and 450 mm are magnified in Figs 19-a and 19-b, respectively.



(a)



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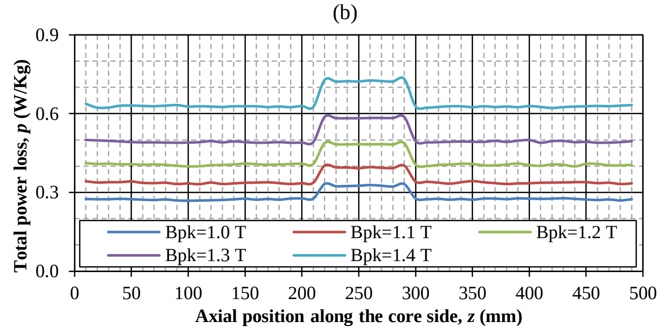

(c)

Fig 15 Specific core loss versus axial position along the core side (a) 10 inter-laminar shorts (b) 20 inter-laminar shorts (c) 30 inter-laminar shorts between one side and bolt hole of stack of laminations at 50 Hz

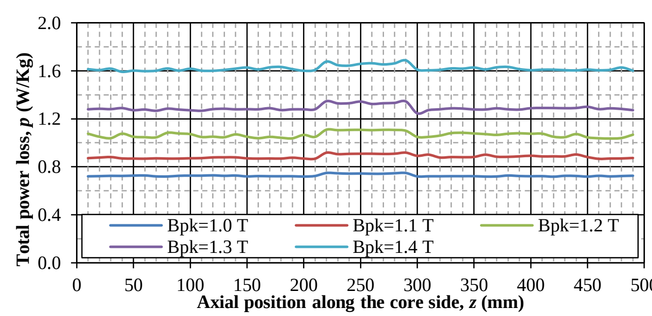

Fig 16 Specific core loss versus axial position along the core side with 5 inter-laminar shorts between one side and bolt hole at 100 Hz

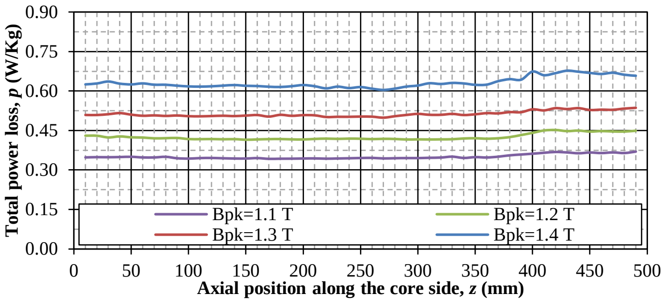

Fig 17 Specific core loss versus axial position along the core side of coil A on side 1; while other side is shorted artificially

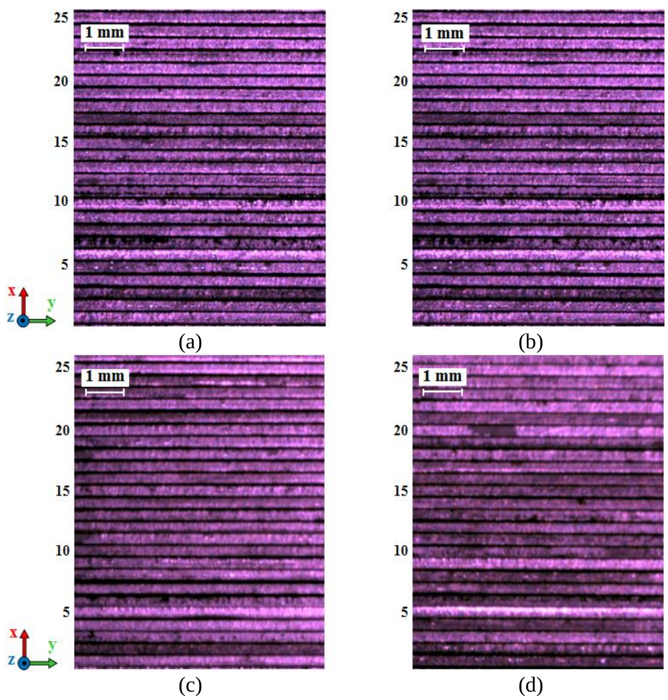

Fig 18 Side view of stack A at distances (a) 300 mm (b) 350 mm (c) 400 mm and (d) 450 mm

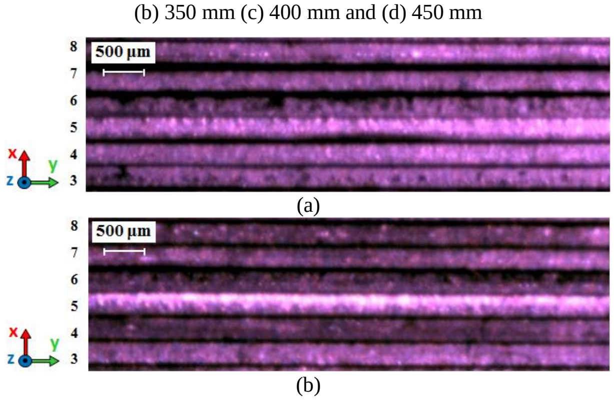

Fig 19 Side view of stack A at distances (a) 400 mm and (b) 450 mm

In the next step of this work, stack A was laminated and laminations number 5 and 6 were replaced. Side of the stack was then scanned under the same conditions as the previous experiment and total power loss of the stack was recorded; the result is shown in Fig 20. It can be seen from Fig 20 that power loss of the stack after replacing the suspected laminations corresponds to the nominal loss of the core. Suspected laminations were then inspected to find out the reason of the inter-laminar short circuit fault.

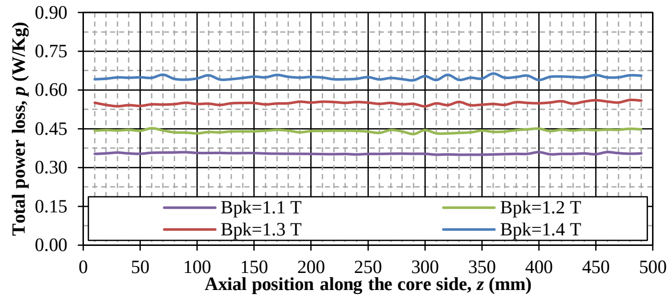

Fig 20 Specific core loss of side 1 of coil A versus axial position while side 2 is shorted artificially; after replacing laminations number 5 and 6

Burr size of the laminations was initially measured at 10 random points at positions of 400 mm to 500 mm using a digital micrometre. The maximum height of the edge burr was less than 12 µm; therefore the extra loss of Fig 17 could not be as a result of high edge burr. Surface resistance close to the edge between the suspected laminations at positions of 100 mm to 130 mm as the perfect zone of the stack and positions of 410 mm to 440 mm as the faulty zone was then measured using Franklin tester provided by Cogent Power Ltd. According to mode A of IEC 404-11 [17], coefficients of surface insulation resistance *C* were calculated. The results are shown in Table I.

Table I Result of Franklin tester on the suspected laminations

Position (mm)	Measured current (mA)		C (Ω Cm^2)	
	Sample # 5	Sample # 6	Sample # 5	Sample # 6
100	10	0	319.28	inf
110	12	0	265.53	inf
120	64	45	47.17	68.44
130	0	0	inf	inf
410	174	435	15.31	4.19
420	216	73	11.71	40.95
430	432	348	4.24	6.04
440	93	112	31.45	25.57

The results show high surface resistance at positions of 100 mm to 130 mm with normal loss; while low surface resistance was detected at positions 410 mm to 440 mm which correspond to the high power loss zone of the stack.

Considering the microscopic pictures of Figs 18 and 19, burr size measurement and the results of the Franklin tester, it was concluded that the increase in loss is related with the lower levels of the surface insulation between the suspected laminations. However it should be noted that in the experimental setup, one side of the stack was totally shorted which is unlikely ever to be the situation in transformer cores.

VII. CONCLUSION

In this paper a non-destructive method was developed to detect inter-laminar faults on magnetic cores by the means of flux injection probe. In this method since the magnetic core is magnetised locally a low power source is required to excite the magnetic core under test; which could be considered as the main advantage of this method. Compared to the other methods, *i.e.* EL CID, interpretation of the output results is much easier and the fault detecting procedure by this method is very quick. However in order to detect inter-laminar fault between a few numbers of laminations, test zone of the core should be magnetised at high frequency and flux density.

In the experimental part of this paper, a prototype of FIP was developed and it was initially calibrated by measuring specific power loss of a stack of Epstein size laminations and applying artificial shorts on either side of the stack. Two case studies were carried out to evaluate the application of the developed system to detect inter-laminar faults on stack of transformer laminations. The results proved that inter-laminar faults between as few as 2 laminations can be detected by this system.

In spite of inter-laminar fault detecting, this method might also be used to verify the quality of the magnetic cores of the electrical machines during core assembling. Power loss of the core at each step of the core assembling can be measured by the FIP. If an inter-laminar fault is located, corrective action can be taken to find and replace the defected lamination. This method could be also implemented to evaluate the quality of the clamping pressure on the magnetic cores after assembling and during usual inspections.

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BIOGRAPHY

Hamed Hamzehbahmani was born in Sanandaj, Iran in 1978. He received the B.Sc. degree in electrical engineering from Birjand University, Birjand, Iran in 2005, the M.Sc. degree in electrical engineering from IUST, Tehran, Iran in 2007 and PhD degree in electrical engineering from Cardiff University, UK in 2014. Between 2005 and 2008 he was employed as a consultant engineer at Moshanir Power Engineering Consultant, Tehran, Iran. In 2008 he joined the school of Engineering at Azad university of Iran as an academic staff. Currently he is a research associate within the high voltage energy system group, Cardiff University, UK. His research interests include eddy current power loss modeling in electrical steels, inter-laminar fault detection in magnetic cores, earthing system and high voltage engineering.

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